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CASE LEARNING BASE ON EVALUATION SYSTEM FOR VESSEL COLLISION AVOIDANCE

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Abstract:

A learning method by recording cases based on an evaluation system for vessel collision avoidance is presented in this paper. The frame model is selected and defined as the case representation method. The basic structure and several processing modules of the evaluation system are discussed. Data fusion methods are used in the system. During processing of the learning case, fuzzy method is also adopted. And finally, the validity of the evaluation system and the learning method is proved by application instance.

Keywords:

Case learning; vessel collision avoidance; evaluation system; data fusion; frame knowledge representation

1. Introduction

Vessel collision avoidance is an important factor for safe navigation. Many work have been done to develop some intelligent decision making systems for solving such problem effectively. But it is quit difficult to put these research works into practice for the vessel collision avoidance process is too depending on human being to be simulated completely. For example, it is navigation experiences but not theories are available in some occasions. CBR (Case-Based Reasoning) is a new way to solve these problems with ill structure or even difficult to be represented by axiom method. CBR emphasized the importance of past experience and insist such idea that human being always recollect the similar past instances and their dispose methods (defined as CASE) to solve current problem. So, CBR is quit fit for the application area with many experiences and they are easy to be represented in the form of CASE. Vessel collision avoidance is such an area.

CASE's representation, organization, retrieve, update and learning are the five main factors in a CBR system. Here, we focus our research on the case representation and case learning in the application of vessel collision avoidance. By extensive study and analysis, frame model is selected as case representation method. An evaluation system for vessel collision avoidance is developed. The evaluation system not only can give some remarks and grade by carrying out a series of analyzing processes upon a set of navigation data for training sailor, but also can be used as a platform to recording vessel collision avoidance case with excellent marks.

The case representation based on frame model for vessel's collision avoidance is described in section 2. Several processing modules of the evaluation system based on data fusion methods are discussed in section 3. By use the fuzzy method, the learning cases by recording some important data obtained from evaluation process is presented in section 4. And finally, application instances are given in section 5 to show the validity of the evaluation system and the feasibility of the learning method.

2. Case representation based on frame model

Frame model is an important and widely used knowledge representation method, and always be regarded as a kind of data structure to record the case hardened or static state. Vessels encounter at sea and present a geometrical "picture". This "picture" can be described as a frame. But vessel collision avoidance is a dynamic process, and how can be recorded as a static state? Fortunately, the most important time point that people concerned about during the whole collision avoidance process is the moment when own vessel takes an action to prevent a collision. So a set of description terms on this point are selected and organized to form the basic structure of the class frame.

Five class frames are defined and the relationships of them are shown in Figure 1.

Ako is the abbreviation for a-kind-of and is used to contact some class frames. The class frame CF_ Environment, CF_Vessel and CF_Action are subclasses of CF_CollisionAvoidance, and CF_Calculation is a subclass of CF_Vessel.

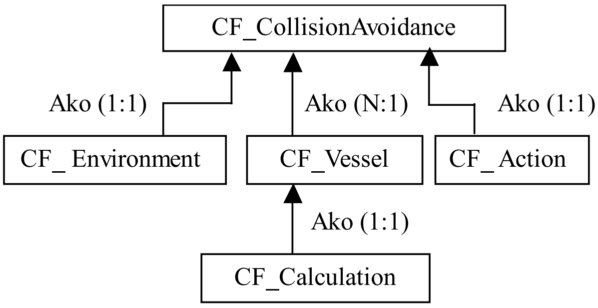

Figure 1. Five class frames and their relationships

CF_CollisionAvoidance records the whole scene when own vessel takes action to avoid collision. CF_ Environment and CF_Vessel record the initial data or information about environment and vessels (including own vessel and target vessel). While some important data or information between own vessel and a target vessel are recorded in CF_Calculation by calculating from those initial data. And the collision avoidance actions are recorded in CF_Action. Structure definitions of above five frames are described in the following.

```
CF_CollisionAvoidance {
   Slot_ID:                value = integer
   Slot_TargetCount:       value = integer
   Slot_Environment:       value = CF_ Environment
   Slot_Vessel:            value = CF_Vessel
   Slot_Action:            value = CF_Action
   Slot_Risk               value = {SMALL, SOME
                           LARGE, TERRIBLE}
}

CF_ Environment {
   Slot_ID:                value = integer
   Slot_TrafficState:      value = {WIDE, LIMITED}
   Slot_Visibility:        value = {IN_SIGHT,
                           RESTRICTED }
   Slot_WindPower:         value = {1, 2, …, 8}
   Slot_WindSpeed:         value = real (kn)
   Slot_WindHeading:       value = real (degree)
   Slot_CurrentSpeed       Value = real (kn)
   Slot_CurrentHeading:    value = real (degree)
   Slot_Rainfall:          value = {DOWNFALL,
                           RAINSTORM, SHOWER, …}
   Slot_Snowfall           value = {FLURRY,
                           HEAVY_SNOW, …}
}

CF_Vessel {
   Slot_ID:                value = integer
   Slot_VesselID           value = integer
   Slot_Role               value = {OWN, TARGET}
   Slot_Type:              value ={POWERBOAT,
                           FISHING, SAILING, …}
   Slot_Length:            value = real (m)
   Slot_SeaGauge:          value = real (m)
   Slot_Course:            value = real (degree)
   Slot_Speed:             value = real (kn)
   Slot_Calculation        value = CF_Calculation
}

CF_ Calculation {
   Slot_VesselID:          value = integer
   Slot_Distance:          value = real (n mile)
   Slot_Bearing:           value = real (degree)
   Slot_DCPA:              value = real {n mile}
   Slot_TCPA:              value = real (minute)
   Slot_Situation          value ={HEADON,
                           CROSSING, OVERTAKING,
                           OVERTAKEN}
   Slot_Stage              value = {FREE, DANGE,
                           CLOSE_QUARTERS}
   Slot_Risk               value = {SMALL, SOME
                           LARGE, TERRIBLE}
}

CF_Action {
   Slot_ID:                value = integer
   Slot_CourseAlterType    value = {STARBOARD,
                           LARBOARD, KEEP}
   Slot_CourseAlterSize:   value = real (degree)
   Slot_SpeedAlterType:    value ={ACCELERATE,
                           DECELERATE, KEEP}
   Slot_SpeedAlterSize:    value = real (kn)
   Slot_PassDCPA:          value = real (n mile)
   Slot_Remark             value ={EXCELLENT,
                           GOOD, OK, PASS}
}
```

3. The evaluation system based on data fusion

The evaluation system is an important part of the navigation simulator for sailor training and can work both under the condition of online and offline. By analyzing a set of initial data collected during student's operation for vessel collision avoidance, a final grade and some comments must be make out. But develop such an evaluation system is not easy to do for some existent difficulties, such as the uncertainty of criterion, diversity of methods and complexity of process. Based on some data fusion methods, an evaluation system for vessel collision avoidance is designed and completed.

3.1. Basic structure of the evaluation system

The initial data are collected periodically. Each cycle data includes the longitude, latitude, course and speed of own vessel and target vessels, as well as the data about wind, current and sea at the time. In order to possess more valuable data or information to give more reasonable evaluation results, not only the each cycle data need to be processed, but also some continuous cycle data need to be associated and syncretized. Four evaluation criterions are selected seriously and accurately, which are crucial for the system success.

(1) Action validity is measured in pass DCPA (Distance of Closest Point of Approach);
(2) Action time is measured in the distance or TCPA (predicted Time to Closest Point of Approach) between own and target vessels when the first collision avoidance action was taken.
(3) Action acceptability is measured in complying with navigation rules;
(4) Action feasibility is measured in perfect cooperation with other vessels'.

Basic structured of the evaluation system is shown in Figure 2 and several important modules are discussed later.

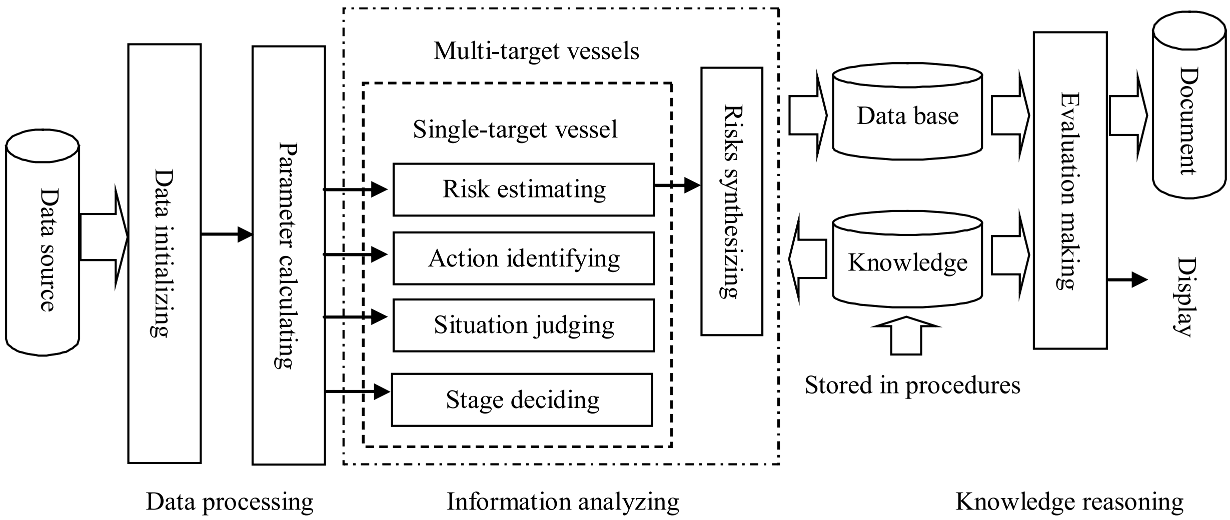

Figure 2. Basic structure of the evaluation system for vessel collision avoidance

3.2. Parameter calculating

Mercator coordinate transform method is used to calculate the bearing and distance between two vessels.

If the longitude and latitude of own vessel and target vessel are denoted by λ_O, ϕ_O and λ_T, ϕ_T respectively, the bearing Bt (radian) and distance Dt (n mile) can be obtained from Eq. (1) to (7).

$$Bt = \arctan(D\lambda / DMP) \tag{1}$$

$$Dt = D\varphi \sec Bt \tag{2}$$

Here

$$D\lambda = (\lambda_T - \lambda_O)\cdot 60 \tag{3}$$

$$D\varphi = (\varphi_T - \varphi_O)\cdot 60 \tag{4}$$

$$DMP = MP(\varphi_T) - MP(\varphi_O) \tag{5}$$

MP is the latitude asymptotic ratio.

$$MP(\varphi) = 7915.70447 \cdot \lg\left[\tan\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)\left(\frac{1-e\sin\varphi}{1+e\sin\varphi}\right)^{\frac{e}{2}}\right] \tag{6}$$

e is the ellipsoid eccentricity ratio, a and b are the half values of the major axis and minor axis.

$$e = \sqrt{1-\left(\frac{b}{a}\right)^2} = \sqrt{1-\left(\frac{6378}{6357}\right)^2} \approx 0.08 \tag{7}$$

Navigation geometry model is used to calculate the relative course, relative speed, DCPA and TCPA between two vessels.

If the speed and course of own vessel and target vessel are denoted by V_O, C_O and V_T, C_T respectively, and B_{rt} is the relative bearing of target vessel, the relative course C_{rt} and relative speed V_{rt} can be obtained from Eq. (8) and Eq. (9).

$$V_{rt} = V_O \cdot \sqrt{1+k^2-2k\cos(\Delta H)} \quad (8)$$

$$C_{rt} = \cos^{-1}\frac{1-k\cdot\cos(\Delta H)}{\sqrt{1-2k\cos(\Delta H)+k^2}} \quad (9)$$

Here $k=\frac{V_T}{V_O}$ and $\Delta H = C_O - C_T$.

So, the DCPA and TCPA of own vessel with target t can be obtained from Eq. (10) and Eq. (11).

$$DCPA_t = Dt\cdot\sin(C_{rt}-B_{rt}) \quad (10)$$

$$TCPA_t = Dt\cdot\cos(C_{rt}-B_{rt})/V_{rt} \quad (11)$$

3.3. Risk estimating and synthesizing

The collision risk between vessels is important factor to affect sailor taking effective actions. The risk degree of own vessel with target t is defined in Eq. (12) to indicate the criticality of the encounter situation.

$$Risk(t)=\begin{cases} 0 & DCPA_t \ge \lambda_{DCPA} \\ \dfrac{1-e^{2\cdot(DCPA_t-\lambda_{DCPA})^2}}{2}+\dfrac{e^{2\cdot TCPA_t^2}}{2} & DCPA_t < \lambda_{DCPA} \end{cases} \quad (12)$$

Here λ_{DCPA} is the threshold of *DCPA* and having different values under the condition of in sight and restricted visibility.

For multi-targets situation, such as N target vessels with $Risk(t)>0$, the united risk degree is synthesized by N local risk degrees.

$$UnitedRisk = \frac{1}{N}\cdot\sum_{i=1}^{N} Risk(i) \quad (13)$$

3.4. Action identifying

There are nine types of collision avoidance actions in the evaluation system. Vessel's actions must be detected from initial data. In order to judge the actions correctly despite the influence of wind and current, some data fusion methods and the MAP rule are adopted to analyze and synthesize M cycles data.

If A_{ij} (i=1, 2…9; j=1, 2…M) is the predicted action A_i being to be taken in cycle j, and $M_{prior}(A_{ij})$ is the prior probability of A_{ij}, which can be obtained from the situation judging module, stage deciding module and navigation knowledge. If O_{ij} (i=1, 2…9; j=1, 2… M) is the observed action O_i taken in cycle j, and $M_{observe}(A_{ij}, O_{ij})$ is the observation probability of O_{ij} on the condition of the predicted action A_i, which can be obtained from initial data. N cycles later, the posterior probability $M_{post}(A_i)$ (i=1, 2…9)of action A_i can obtain from Eq. (14).

$$M_{post}(A_i)=\sum_{j=1}^{M}\sum_{i=1}^{9} M_{prior}(A_{ij})\cdot M_{observe}(A_{ij},O_{ij}) \quad (14)$$

According to MAP rule, the identified action is $\max[M_{post}(A_i)]$.

The cycle number M has grate influence upon the identifying precision and reliability. Undergoing many tests, the range of M is select as 5~10.

3.5. Evaluation making

The final grade is given by Eq. (15).

$$Grade = a_D\cdot M_D(DCPA_t)+a_T\cdot M_T(t) + a_N\cdot M_N(n)+a_R\cdot M_R(r) \quad (15)$$

$M_D(DCPA_t)$, $M_T(t)$ and $M_N(n)$ are the evaluating function for final pass DCPA, action time and action number, and they are all normal distribution functions.

$$M(x)=e^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad (16)$$

For example, under the condition of restricted visibility, σ=0.5 and μ=2 in $M_D(DCPA_t)$, σ=2 and μ=5 in $M_T(t)$, σ=2 and μ=1 in $M_N(n)$.

$M_R(r)$ is the ratio of the cycle numbers complying with rules to total cycle numbers.

The a_D=0.4, a_T=0.3, a_N=0.1and a_R=0.2 are the weights determined in advance.

The discussions about data initializing module, situation judging module and stage deciding module can be found in Reference [1]~[3].

4. Learning case based on fuzzy method

From the performance of .the evaluation system, the grade and remarks on the trainer's operations for collision avoidance can be obtained, and some operations with excellent grade can also be recorded as typical cases. It is quit easy to extract the quantitative data such as the course, speed, DCPA, TCPA and so on in CF_Vessel and CF_ Calculation from evaluation system. But for the qualitative description, such as the risk in CF_CollisionAvoidance and CF_ Calculation, some fuzzy methods must be adopted to transform the quantitative data, such as the risk degree calculated from Eq. (12) and Eq. (13), to the qualitative description, the fuzzy words: SMALL, SOME LARGE and TERRIBLE. The membership distribution of the risk degree is shown in Figure 3.

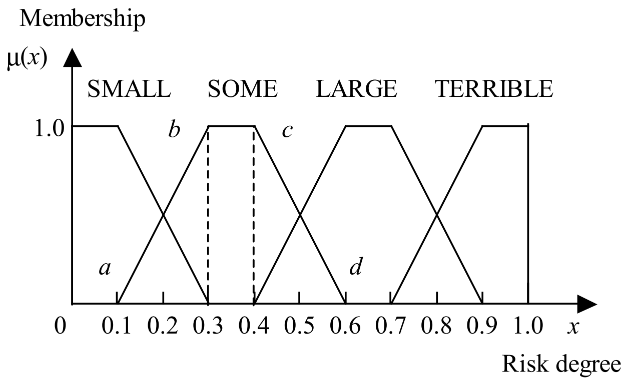

Figure 3. The membership distribution of the risk degree

If each trapezoid is defined by a set of four parameters, $\{a, b, c, d\}$, the uniform membership functions can be given by Eq. (17).

$$\mu(x)=\begin{cases} 5\cdot(x-a) & a\le x<b \\ 1 & b\le x<c \\ -5\cdot(x-d) & c\le x<d \\ 0 & others \end{cases} \tag{17}$$

5. Application instance

An application instance of the evaluation system is shown in Figure 4.

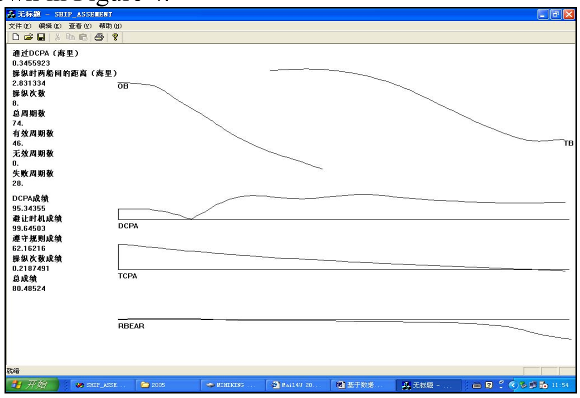

Figure 4. An application instance of the evaluation system

The traces of two vessels are displayed on the top right side of the figure. The below three curves reveal the variation of DCPA, TCPA and bearing between vessels. At first, two vessels are in head on encounter situation, and having a small DCPA. According to navigation rules, each vessel should turn to starboard to make a large pass DCPA. The final grade and remarks are given on the left side of the figure. Because the final pass DCPA is not sufficient, the grade made by evaluation system is 80.

Figure 5 shows recording this instance as a collision avoidance case. Those slot's values not be able obtained from the instance keep blank.

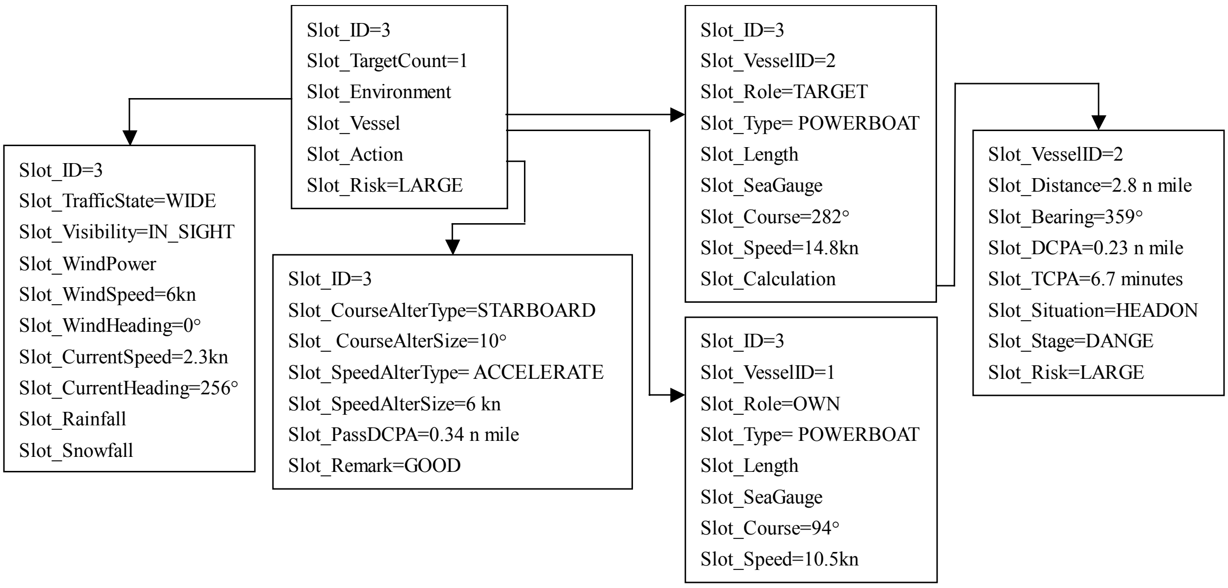

Figure 5. Learning case by recording

6. Conclusion

Based on the evaluation system for collision avoidance, the case can be learned by recording some important data or information during the process of evaluating. The performance validity of the evaluation system is crucial for the feasible of this case learning method. So, more research work needed to be done to improve the performance of the evaluation system and the efficiency of the learning method. On the other hand, studying and developing the effective methods to retrieve, update and use these cases is our next research object.

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